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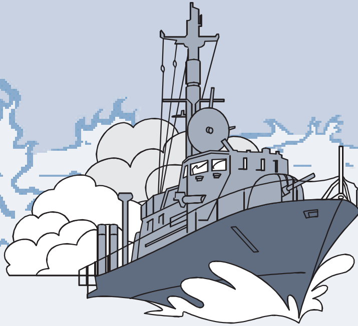

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CAD/CAM/CIM Requirements For A World Class Commercial Shipyard

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ABSTRACT

With their ongoing reentry into the international shipbuilding market, U.S. shipyards are focusing on the strengths and potential of computer-aided design/computer-aided manufacturing/computer-integrated manufacturing, or CAD/CAM/CIM. World-class commercial shipyards and software suppliers in Europe and Japan have advanced the state of the art of CAD/CAM/CIM and offer much for U.S. yards to learn. Indeed, they have proven generous in sharing their knowledge with the U.S., as evidenced during the conduct of the recent National Shipbuilding Research Program "Evaluate the Shipbuilding CAD/CAM Systems" Project.

The primary goal of Phase I of the Project was to identify key features of CAD/CAM/CIM implementations at world-class shipyards that most significantly contribute to the success of those shipyards in commercial shipbuilding and deliver this information to U.S. shipyards. That goal has been accomplished and the results presented at a CAD/CAM/CIM workshop at the 1996 Ship Production Symposium. This paper reports on Phase II of the CAD/CAM/CIM project, which built upon the knowledge gained in Phase I. In Phase II, the Project Team developed a set of 70 technical requirements for a world-class ship design and production CAD/CAM/CIM system that is future-oriented. In addition, the Team described links between the technical side of shipbuilding and the business side, illustrating the business value of the technical requirements in particular and advanced CAD/CAM/CIM in general.

It is hoped that the technical requirements and business links will provide U.S. yards with guide posts which will help those yards not only catch up with, but leapfrog, world-class technology and establish a competitive presence in the international shipbuilding market.

Key words: CAD, CAM, CIM, Business, Computer, Shipyard, Shipbuilding, Design, Requirement

NOMENCLATURE

CAD Computer-Aided Design
CAM Computer-Aided Manufacturing
CIM Computer-Integrated Manufacturing

INTRODUCTION

This paper is based work performed during the conduct of Phase II of National Shipbuilding Research Program (NSRP) Project 4-94-1 to evaluate world-class shipbuilders' CAD/CAM/CIM system implementations. Five U.S. shipyards (Avondale Industries, Bath Iron Works, McDermott Shipbuilding, Newport News Shipbuilding and National Steel and Shipbuilding) participated in this study along with personnel from University of Michigan, Proteus Engineering and Cybo Robots. All of the individuals were key contributors to the practical application of computer aided manufacturing technology in the U.S. shipbuilding industry.

The CAD/CAM/CIM Project comprised three phases, as follows:

- Phase I - Evaluate Existing Systems - Visit world-class shipyards in Europe and Japan and learn about state of-the-art shipbuilding CAD/CAM/ CIM implementation approaches.
- Phase II - Requirements - Build upon the knowledge gained in Phase I to develop a set of requirements for a competitive, future-oriented shipbuilding design and production CAD/CAM/CIM system.
- Phase III - Workshops - Prepare for and conduct workshops that show how CAD/CAM/CIM technology requirements relate to shipyard management from a business perspective.

The Phase I results were presented at a two-day workshop and a paper [1] at the 1996 Ship Production Symposium and in a formal report [2]. In-depth descriptions were provided of the visits to shipyards, allied industries and software developers. It was noted that, while aggressive business practices were keys to ensuring the success of high technology shipyards, those shipyards used CAD/CAM/CIM to gain competitive advantages over low technology yards through approaches such as:

- Development of more complete, consistent, production-oriented design packages;
- Earlier project schedule and planning simulations; and,
- Improved ability to coordinate design, procurement and production within the entire enterprise (shipyard, vendors, customers and regulatory bodies).

Without exception, the shipyards and software vendors that the Team visited continue to strive for improvement. Example future plans included [2]:

- More complete product modeling, including integration with shipyard process modeling, especially in the robots areas;
- Increased automation in the design process, using "rules" to facilitate the CAD process and concurrently incorporate production process considerations;
- Increase automation in production, again, with an emphasis on robots;
- Integration with economic decision making;
- Improve cost and performance computing hardware;
- Improve product model databases and develop interfaces that are more industry standard;
- Develop Windows NT versions of product model software;
- Develop knowledge-based software;
- Improve visualization capabilities, including capability for walk-throughs;
- Enhance computational and design capabilities (e.g., hull form development and computational fluid dynamics);
- Provide integration of product model systems with third party programs (e.g., material management);
- Develop improved tools for quick development of designs for tendering; and,
- Develop enterprise-wide automation and communication.

The following sections describe key aspects of the Phase II effort [3], including a description of the requirement development process; a presentation of the CAD/CAM/CIM requirements developed by the Project Team; a description of a requirement selection methodology; and conclusions and recommendations resulting from lessons learned during the conduct of the Project.

THE REQUIREMENT DEVELOPMENT PROCESS

Requirements development is one stage in the software life cycle process. This process may be summarized by the following steps:

1. Determine user needs
2. Develop software requirements
3. Develop software specifications
4. Conduct programming
5. Test and debug
6. Implement, train users
7. Maintain
8. Decommission.

The steps most relevant to this paper are (1) and (2) which parallel Phases I and II of the NSRP Project.

Where Requirements Fit Within the Software Development Process

In this creative process, requirement descriptions usually tend to be "generally poor," not because of any fault of the software designers or of the process, but rather because all requirements are not known until the software is developed and users try it out [4]. Because the rest of the design process is based on the requirements, every effort should be made to make the requirement descriptions as complete, accurate and precise as possible; this was the goal of the Project Team.

Requirements have several characteristics. They are:

- Derived based on an understanding of user needs,
- Written statements,
- Tell what the software must do, and they
- Tell how the software is structured.

Requirements do <u>not</u> tell how the software is programmed.

There is a difference between the goals of the NSRP Project and a ship production software development project. The CAD/CAM/CIM Project did not result in actual software. Rather, ship production needs have been identified and CAD/CAM/CIM requirements have been developed.

The requirements should be viewed collectively as the needs of future-oriented, commercial shipbuilding CAD/CAM/CIM software. The requirements are not to be thought of as comprising modules of such software, but rather as features which are to be found within the software. The requirements do not tell how to design the software, they simply state needs the software must fulfill. Thus, various solutions may exist, each of which may meet the requirements, but in different ways. There is no single "right" solution.

Testing

Testing is the approach that software developers use to detect and correct errors. It has been stated that "more than half the errors are usually introduced in the requirements phase"[7]. To prevent migration of errors onward to the specifications phase and beyond, testing should be carried out as part of the development of requirements. In fact, testing and error correction should be carried out at each phase of software development. For example, the following checklist, adapted from [6] and [7], may be used to test requirements.

- <u>Complete</u> - All items needed to specify the solution to the problem have been included.
- <u>Correct</u> - Each item is free from error.
- <u>Precise, unambiguous, and clear</u> - Each item is exact and not vague; there is a single interpretation; the meaning of each item is understood; the description is easy to read.
- <u>Consistent</u> - No item conflicts with another item.
- <u>Relevant</u> - Each item is pertinent to the problem and its solution.

- Testable - During program development and acceptance testing, it will be possible to determine whether the item has been satisfied.
- Traceable - Each item can be traced to its origin in the problem environment.
- Feasible - Each item can be implemented with the available techniques, tools, resources, and personnel, and within the specified cost and schedule constraints.
- Free of unwarranted design detail - The requirements are statements of what must be satisfied by the problem solution, and they are not obscured by proposed solutions to the problem.
- Manageable - The requirements are expressed in such a way that each item can be changed without excessive impact on other items.

CAD/CAM/CIM REQUIREMENTS

The CAD/CAM/CIM requirements are those elements that were identified by the Project Team as necessary for a competitive, future-oriented shipbuilding design and production CAD/CAM/CIM system.

Requirements Listing

A requirements listing was developed and refined as the project progressed. This listing formed a basis for questions asked and information gathered during shipyard, vendor and allied industry visits by the Team. The requirements were organized to be consistent with U.S. shipyard typical practices. All requirements were first grouped into the general areas of Design, Production, Operations Management and Umbrella (the Umbrella area covered requirements generally common to one or more of the other areas). The requirements were further subdivided into detail areas as follows.

Design
- Conceptual/Preliminary Design
- Functional Design
- Detailed Design

Production
- Fabrication Processes
- Joining and Assembly Processes
- Material Control
- Testing and Inspection

Operations Management
- High-Level Resource Planning and Scheduling
- Production Engineering
- Purchasing/Procurement
- Shop Floor Resource Planning and Scheduling

Umbrella
- Umbrella

How Requirements are Described

Requirements are described on 'requirement sheets.' One sheet containing the information described below is provided for each requirement.

- Requirement - Descriptive title of the individual requirement.
- State of development - Indication of how far the requirement has advanced toward actual practice: conceptual stage, initial development, prototype testing, proprietary versions and available on the market. A requirement may be at several stages of development. For example, a requirement may exist in software that is proprietary in one shipyard, yet also be available on the market in other software. The most advanced of the choices is provided on the requirement sheet.
- Description - Definition of the requirement and explanation of its role in the context of a CAD/CAM/CIM system.
- Potential business benefits - Description of how the requirement can help a shipyard from the business perspective, for example, in the areas of innovation, addressing a customer's needs or through optimization.
- General area - Denotes which of four overall categories apply to a given requirement.
- Detail area - Denotes which of 13 particular categories apply to a given requirement.

The full list of requirements is presented in the Appendix, grouped in this two-tier manner.

REQUIREMENT SELECTION METHODOLOGY

General

Not all shipyards will want, need or be able to afford all of the requirements listed in the previous section. Thus, a selection methodology is needed to choose those requirements that will best serve the needs of each particular shipyard. As a first step in this methodology, shipyard upper management should define their strategic plan, considering elements such as the following:

- Market leadership goals,
- Strategic direction of the shipyard,
- Planned response to market needs,
- Costs of implementing CAD/CAM/CIM,
- Design and production processes within the shipyard,
- Relationships with suppliers and vendors, and
- Relationships with customers.

Whatever the detail of the strategic plan, of paramount importance is the involvement and buy-in of upper management with regard to CAD/CAM/CIM selection and implementation. Involvement commonly includes educating upper management in the general capabilities of CAD/CAM/CIM. Without the involvement of upper management, there may be no connection between the CAD/CAM/CIM system that is selected and the business results envisioned in the shipyard's strategic plan [8].

CAD/CAM/CIM selection is a melding of business and technology in the shipyard. In a larger sense, the selection methodology may be viewed as a way to align technology with business results, which is a major theme of this paper. Two key steps for achieving this alignment are to [8]:

- Plan for innovation, customization, and optimization, and
- Use the theory of constraints to identify priorities.

The sections below describe these two steps; show how they are used as part of a selection methodology; and provide examples from industry that illustrate the methodology.

Innovation, Customerization and Optimization

CAD/CAM/CIM technology requirements may be aligned to business objectives by using the following equation [8]:

$$MS_1 \times MS_2 \times MS_3 = \text{Profit} \qquad (1)$$

Where,

MS_1 = Market Size,
MS_2 = Market Share, and
MS_3 = Margin on Sales.

For example, if a shipyard has a 10% share (MS_2 = 10%) in a \$100 Million market (MS_1 = \$100 Million), and its margin on sales are 20% (MS_3 = 20%), then,

\$100 Million x 0.10 x 0.20 = \$2 Million Profit.

The thinking in this approach is that everything a company does should improve at least one of these three areas. Thus, these areas can be used to track trends and evaluate alternative business actions. Looking at each area in detail provides further insight as to their use:

Market Size (MS_1) - Create or participate in attractive markets through new product innovation. **Innovation** drives market size.
Market Share (MS_2) - Win market share against competitors by providing products and services customers prefer. **Customerization** drives market share.
Margin on Sales (MS_3) - Earn healthy margins by some combination of earning a premium price and/or being the lower-cost provider. **Optimization** drives margin on sales.

Figure 1 expands upon these areas. Note that the three areas are not mutually exclusive; a shipyard may simultaneously participate in two or even all three areas, especially if the yard is working several projects, some at the conceptual and marketing stage, others at more advances stages of production.

Use of the Theory of Constraints to Identify Priorities

The Theory of Constraints is a way to focus on where to improve a process. For example, a shipyard may want to improve throughput in a plate nesting and cutting operation. At first, the best approach may seem to be replacing an existing manual cutting operation with robotics. Closer study may show that robotic cutting would reduce the number of personnel in the operation, but not increase throughput, because of downtime while waiting to receive cutting data: robots or people could work only a fraction of the time, and must wait the rest. Thus, throughput would remain as before. In this case, the constraint is the lofting operation, which is slowing down the overall throughput. If the lofting time is decreased (for instance, through CAD/CAM automation), then the constraint is removed.

Knowing the constraints in the shipbuilding process will help a shipyard focus on how CAD/CAM/CIM technology can improve that process. The principles of the Theory of Constraints may be summarized as follows [8]:

- The throughput of an entire system is held back by constraints. Constraints may be both physical (e.g., limited throughput of computer systems) and non-physical (e.g., bureaucratic procedures or competition between departments); thus, a thorough knowledge of the process being evaluated is mandatory.
- Most systems have relatively few real constraints. Improvements at just these constraints will dramatically improve throughput. However,

  "gains" in areas where there are no constraints has zero value.
- Traditional measures of productivity fail to recognize the importance of constraints. For example, a 10% productivity improvement on a \$10/hour clerical job might really be worth \$1000/hour to the company, while a 30% improvement on a higher profile \$100/hour job may prove worthless.
- Constraints provide a focal point for managing the entire system.
- Constrained processes should run as close to 100% efficiency as possible. Never starve them for necessary inputs. Keep non-productive times (e.g., set-ups) to a minimum.
- In manufacturing operations, inventories usually pile up in front of bottleneck operations.

The ultimate constraints, which may sound all too familiar to those in the shipbuilding industry, are:

- Markets with slow growth (for U.S. shipbuilders, the traditional market is actually shrinking, through cutbacks in Navy orders);
- Inability to break through the competition (the Koreans increase their capacity, the Japanese increase their efficiency and the Europeans remain fiercely competitive); and
- Difficulty in optimizing processes and products to achieve higher margins (changing processes, software and production lines is daunting).

The following questions define whether something really is a constraint.

- Back-up - Is this operation a back-up for work?
- Impact on product delivery - If this process is backed up for a day, is delivery delayed for a day?
- Impact on $(MS)^3$ - If this operation were performed better, would that improvement be reflected in improved market size, market share or margins?

BUSINESS AND MARKET GOALS

MARKET SIZE	MARKET SHARE	MARGIN ON SALES
- today? - trend for future?	- today? - trend for future?	- today? - trend for future?
⇓	⇓	⇓

CUSTOMER INTEREST	CUSTOMER CHOICE	CUSTOMER LOYALTY
drives market size	drives market share	internal costs drive margin on sale
⇓	⇓	⇓

PROCESS PERSPECTIVE

INNOVATION	CUSTOMERIZATION	OPTIMIZATION
Innovation creates customer interest and increases the market for new products. The goal is to be not just first, but right to market. For new features, aim to delight customers.	Customerization satisfies customer needs and maintains or grows market share. The process goes beyond concurrent engineering to sharing knowledge between all functions, customers, and suppliers.	Optimization increases perceived value and lowers costs, leaving higher margins for the company. Creating and maintaining customer loyalty decreases the cost of sales and increases profits. Lower costs, with on loss of perceived value, contribute directly to the bottom line.
⇓	⇓	⇓

TECHNOLOGY ALIGNMENT

CAD/CAM/CIM TO SUPPORT INNOVATION	CAD/CAM/CIM TO SUPPORT CUSTOMERIZATION	CAD/CAM/CIM TO SUPPORT OPTIMIZATION
could include 2D and 3D brainstorming, what-if analysis, visualization, simulation, getting physical fast, rapid tooling. The tool must be easy for innovators, who will not be full-time users.	should link diverse and broadly dispersed knowledge workers. In addition to a wide variety of applications, networking, data sharing, and support are important issues.	will often include computing intensive applications. May be able to justify "best in breed" solutions that integrate with the primary tools for design review. (Without some level of integration, optimization in on area may adversely affect another.)

Figure 1
Framework for Aligning Business, Process and Technology
(Based on Figure III-7 of [8])

Selection Methodology

The selection methodology is a way for a shipyard to choose its CAD/CAM/CIM system. As mentioned above, this process must involve upper management and must be based on achieving business results. The steps of the selection methodology are as follows (see Figure 2).

1. <u>Conduct business assessment</u> - The real objective is "business results," so begin by defining the shipyard's goals in the areas of market size, market share and margins. This is commonly a task of top management. The goals are stated in a shipyard's business strategy.
2. <u>Define new processes</u> - New processes (which may be variations of existing processes) will be necessary as a result of the new direction defined in Step 1; old processes, even with new tools, will yield old results. The processes may run in parallel, and will comprise one or more of the *innovation, customerization and optimization* areas. It is important to define the process before choosing requirements or technologies.
3. <u>Identify priorities</u> - Use the Theory of Constraints to identify problem areas in processes. This is a critical link between *productivity improvements* and *business benefits*.
4. <u>Select requirements</u> - Select appropriate requirements that will address the priorities of Step 3. Many of the requirements of this paper should apply to U.S. shipyards' priorities (modifications or additions will be appropriate in certain cases). While all the requirements may look attractive, care should be taken to select only those applicable to the identified priorities.
5. <u>Select technologies</u> - Technologies (e.g., a new CAD system) should be selected to meet the requirements of Step 4.

This selection methodology is business driven and not technology driven. Shipyards may be tempted to purchase new technologies (such as a product model CAD/CAM system) without thinking through the implications at the business level. Will the new CAD/CAM system reduce or remove a constraint in the shipyard? Sometimes that question is assumed to be "yes" but not actually investigated.

In conjunction with this selection methodology, shipyards should ensure that the expectations of affected people are set. Changes in processes mean that changes in behavior and organization are often necessary. For example, CAD/CAM/CIM tools may eliminate the need for a lofting department. Loftsmen may find themselves part of a design team or they may be shifted to production. In either new role, the loftsmen's prior experience in ship hull forms would be applied to a part of a new process. The loftsmen would be expected to learn and contribute to the new process and understand that it is different from the process they had participated in prior to the adaptation of CAD/CAM/CIM. Generally, everyone involved in CAD/CAM/CIM changes must be aware of the expectations placed upon them, from top management to shop personnel.

Examples from Industry

To illustrate the selection methodology, several examples have been chosen from industry. These examples were observed by members of the Project Team. The requirements were chosen from the list in the Appendix. One example illustrates each of the three business areas:

1. Conduct Business Assessment

⇓

2. Define New Processes

⇓

3. Identify Priorities

⇓

4. Select Requirements

⇓

5. Select Technologies

Figure 2
Selection Methodology

Market Size (MS_1) - Innovation: Odense Steel Shipyard
Market Share (MS_2) - Customerization: Japanese CIM Project
Margin on Sales (MS_3) - Optimization: Black and Veatch

Each is summarized in Table 1 and discussed in the following paragraphs.

Innovation: Odense Steel Shipyard - Odense Steel Shipyard is located in Odense, Denmark. The shipyard makes use of a number of CAD/CAM/CIM systems, integrated to work together, including HICADEC, NAPA, PROMOS, NISA and DPS. The yard carries out the design as well as the production of large, ocean-going ships, typically VLCCs and containerships.

Odense has developed a balance between manual and automated systems in areas such as material handling, marking, cutting, positioning and welding. A key goal of the yard is controlling the shipbuilding process. Toward this end, there is a high degree of automation in design and planning, including production simulation, all readily addressed by their CAD/CAM/CIM system. On the other hand, there is manual intervention in much of material handling, marking and welding. Automation is evident in repetitive process, such as fabricating built-up profiles and (using robots) certain well-defined welding tasks. Trends at the yard include increasing the proportion of automation and further refining the CAD/CAM/CIM system, both as means to help increase production efficiency, as measured by minimized build time. Through its present strategy, efficiency is increased both directly (e.g., by decreased welding times through robotic welding) and indirectly (e.g., by driving increased accuracy and quality to meet robotic welding tolerance requirements).

As shown in Table I, Odense's business assessment targeted the marketing segments of double hull VLCCs and large containerships. A recent Odense initiative was aimed at innovation (increasing market size through innovation -- MS_1). The idea was to construct containerships of 6000+ TEUs, larger than any previous size, thus permitting owners to reduce the number of ships in their fleets as well as realizing other business-related advantages.

As part of the successful design, Odense maximized the number of containers for a given hull volume through a new type of container guide. The new guide increased the number of containers that the ship could carry, but introduced a production constraint: vendors do not produce structural shapes of sufficient accuracy. The yard decided to cut and form the container guide shapes in house, within the context of requirement 19, "Processes to Cut/Form Structural Plates and Shapes." The yard had to review their existing capabilities for generating NC data to loft, nest, bevel, cut and schedule work into their production area.

In the resulting process, the yard began with steel plate, carefully specified to be within acceptable thickness tolerances. The plate was cut, edge treated and fabricated into container guides. The operation, from generating NC data to fabrication, has proved successful and the first ship of this type has been launched.

Customerization: Japanese CIM Project - The Japanese CIM Project was conducted in the late 1980s and early 1990s [5]. The project was a cooperative effort among Japanese shipyards and was aimed at strengthening the management structure in the participating yards through emerging computer-based technology. The effort was aimed at countering the shipbuilding competition from Korea and maintaining Japan's share of the market.

This project comprised several initiatives, including development of a conceptual version of a 'frame model.' The frame model is a shipbuilding industry computer integrated manufacturing (SICIM) methodology. It encompasses design and production and was designed to be flexible enough to be expanded in scope. The methodology was aimed at changing the ship design and production planning process.

The constraint addressed by the project was a lack of integrated design and production capability. If this constraint could be reduced, the Japanese projected that their competitive position with the Koreans would improve to such an extent that the Japanese market share would benefit. The effort was carried out by teams from seven Japanese shipyards: Mitsui Shipbuilding, Sumitomo Heavy Machine Industry, NKK, Kawasaki Heavy Industry, Ishikawa-Jima Takuma Heavy Industry, Hitachi Shipbuilding and Mitsubishi Heavy Industry. Each team addressed a separate task. For example, the Mitsubishi Heavy Industry Team's goal was two-fold:

- Confirm whether it is possible to enter design information about curved parts in an expanded product model, and,
- Find out if simulation based design facilitates generation of a

preliminary body of design information and is useful for scheduling.

As the above description of scope makes evident, the Japanese CIM Project encompassed an 'enterprise product model,' as defined in Requirement 64 (a central database that encompasses not only the technical aspects of design, but planning and scheduling aspects as well). The Japanese were well equipped to take on such a task, given their history of successful CAD/CAM programs, such as HICADEC, used at Hitachi Shipbuilding in Japan and Odense in Denmark. The project results comprise conceptual developments and pilot studies in selected areas. The efforts of the teams were reported individually, thus becoming a source of data for each yard to continue further development on its own.

Optimization: Black and Veatch - Black and Veatch is an engineering and construction firm specializing in the fields of energy, environment, process and buildings. Headquartered in Kansas City, Missouri, where it was founded in 1915, the firm provides comprehensive planning, engineering design, and construction services to utilities, commerce, industry and government agencies [9]. Since the late 1970s, the company's president and management have backed the expenditure of more that $50 million on CAD/CAM/CIM technology development. The result of the effort was the development of Powrtrak, a proprietary software program used to design power plants for electric utilities. Among other features, Powrtrak allows changes made by any user to be stored systemwide [10]. This is a 'datacentric' concept, and

SELECTION METHODOLOGY	ODENSE STEEL SHIPYARD	JAPANESE CIM PROJECT	BLACK AND VEATCH
1. Conduct Business Assessment	Need for a new product in the containership field	Need to increase market share, especially with regard to Korea	Need to increase margin in the power plant industry
⇓	⇓	⇓	⇓
2. Define New Processes	Process to produce accurate container guides	Process to efficiently carry out ship design and production planning	Process to reduce the costs associated with risk
⇓	⇓	⇓	⇓
3. Identify Priorities	Constraint: vendor-produced structural shapes decreased yard's capability for accuracy or speed of production of guides	Constraint: lack of integrated design/production capability	Constraint: insufficient availability of design and production information to all project participants
⇓	⇓	⇓	⇓
4. Select Requirements	19. "Processes to Cut/Form Structural Plates and Shapes"	64. "Enterprise Product Model"	61. "Full Data Access (Read Only) to All Project Participants"
⇓	⇓	⇓	⇓
5. Select Technologies	Automated line to cut and fabricate container guide shapes	Conceptual version of integrated design and production product model CAD/CAM/CIM system	Integrated design and production CAD/CAM/CIM system with remote access capability

Table I
Industry Examples of Use of Selection Methodology

prevents duplication of data by allowing it to be entered Powrtrak allows changes made by any user to be stored systemwide [10]. This is a 'datacentric' concept, and prevents duplication of data by allowing it to be entered only one time in a power plant product model. An allied feature of the system is that any operator may view (but not necessarily change) any data in the product model.

Powrtrak overcame various constraints found in traditional design approaches. For example, in traditional approaches, elements (e.g., a pump) may be represented numerous times in various parts of the design (e.g., system diagrams, composite drawings, weight estimate and bill of materials). In the traditional approach, a change in one representation will not automatically be changed on the others, resulting in potential configuration management errors. Powrtrak ensures errors of that type are not made. Also, a designer of one system, with a question about another system, may access the other system's data. This is a version of Requirement 61, "Full data access (read only) to all project participants." An example of the effect of Powrtrak, is that a 400-megawatt fossil-fuel and pulverized-coal power plant that would have taken 60 months to design and build before Powrtrak can now be finished in 29 months [8].

Powrtrak and other software innovations at Black and Veatch are credited with boosting the company's revenue from $277.7 million in 1988 (when Powrtrak was implemented) to $693.4 million in 1993. The software helped the company submit lower bids (increasing margin in its industry), snare new business and boost market share [8].

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In the course of carrying out the Phase II effort, the PROJECT Team concluded that:

- CAD/CAM/CIM is necessary for U.S. shipyards to become competitive with overseas yards.
- Involvement of upper management is key to ensuring that CAD/CAM/CIM is implemented in a way that will best meet a shipyard's business goals.
- A business strategy is necessary in order to provide a framework within which to select the requirements of a CAD/CAM/CIM system that is best suited for a given shipyard.
- A set of requirements can describe the elements necessary for a competitive, future-oriented shipbuilding design and production CAD/CAM/CIM system.
- Participation in multi-organizational projects, such as NSRP projects, MARITECH projects, and the development of STEP, can help shipyards enhance their competitive position.

Recommendations

The Project Team recommended that shipyards implement CAD/CAM/CIM and that upper management is involved in the implementation process. While technical expertise resides in the middle management, line management, professionals and production personnel, the drive, guidance and support must originate at the top. The Project Team recommended that upper management's involvement include becoming familiar with relevant CAD/CAM/CIM issues at the executive level, learning how CAD/CAM/CIM can help meet a shipyard's business objectives, developing their shipyards' business strategy, and supporting the efforts of other shipyard management and technical personnel in selecting and implementing CAD/CAM/CIM in their yards. The Team recommended shipyard participation in multi-organizational projects. Finally, the Team recommended that shipyards balance CAD/CAM/CIM development within and outside the shipyard. Most yards will find it most effective to use commercial off-the-shelf programs, tailoring those programs to a small extent to suit unique needs of their shipyard situation.

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APPENDIX - LISTING OF REQUIREMENTS GROUPED INTO GENERAL AND DETAILED CAD/CAM/CIM AREAS

GENERAL AREA	DETAIL AREA	NO.	REQUIREMENT NAME
DESIGN	Conceptual/Preliminary Design	1	Concept/Preliminary Design Engineering Analysis Tools
		2	Reusable Product Model
		3	Develop Initial Build Strategy, Cost and Schedule Estimates
		4	Classification/Regulatory Body and Owner Compliance Support
	Functional Design	5	Connectivity Among Objects
		6	Tools to Develop Standard Parts, Endcuts, Cutouts and Connections
	Detailed Design	7	Automated Documentation
		8	Detail Design Engineering Analysis Tools
		9	Design for Fabrication, Assembly and Erection
		10	Linkage to Fabrication Assembly and Erection
		11	Automatic Part Numbering
		12	Interference Checking
		13	Linkage to Bill of Material and Procurement
		14	Weld Design Capability
		15	Coating Specification Development
		16	Definition of Interim Products
		17	Consideration of Dimensional Tolerances
		18	Context-Sensitive Data Representations
PRODUCTION	Fabrication Processes	19	Processes to Cut/Form Structural Plates and Shapes
		20	Documentation of Production Processes
		21	Information Links to Production Work Centers
		22	Piece and Part Labeling
		23	Creation of Path or Process Programs for NC Machines and Robots
		24	Development of Interim Product Fabrication Instructions
		25	Simulation of Fabrication Sequences
	Joining and Assembly Processes	26	NC Programs for Joining and Assembly
		27	Automated Subassembly/Assembly Processes

APPENDIX (Continued)
Listing of Requirements Grouped into General and Detailed CAD/CAM/CIM Areas

GENERAL AREA	DETAIL AREA	NO.	REQUIREMENT NAME
PRODUCTION	Joining and Assembly Processes	28	Programmable Welding Stations and Robotic Welding Machines
		29	Location Marking for Welded Attachments
		30	Definition of Fit-Up Tolerances
		31	Control of Welding to Minimize Shrinkage and Distortion
		32	Programming for Automated Processes
		33	Definition of Fit-Up Tolerances for Block Assembly Joints
	Material Control	34	Capabilities for Material Pick Lists, Marshaling, Kitting and Tracking
		35	Tracking of Piece/Parts Through Fabrication and Assembly
		36	Communication of Staging and Palletizing Requirements to Suppliers
		37	Documentation of Assembly and Subassembly Movement
		38	Handling and Staging of In-Process and Completed Parts
	Testing and Inspection	39	Testing and Inspection Guidelines
OPERATIONS MANAGEMENT	High-Level Resource Planning and Scheduling	40	High Level Development of Build Strategy
		41	Order Generation and Tracking
		42	Performance Measurement
		43	Production Status Tracking and Feedback
		44	Inventory Control
		45	High Level Planning and Scheduling
	Production Engineering	46	Development of Production Packages
		47	Development of Unit Handling Documentation
	Production Engineering	48	Parts Nesting
		49	Development and Issue of Work Orders and Shop Information
	Purchasing/Procurement	50	Material Management
	Shop Floor Resource Planning and Scheduling	51	Provision of Planning and Scheduling Information to Shops
		52	Work Order/Work Station Tracking and Control
		53	Detailed Capacity Planning for Shops and Areas
		54	Collect and Calculate Costs for a Major Assembly

APPENDIX (Continued)
Listing of Requirements Grouped into General and Detailed CAD/CAM/CIM Areas

GENERAL AREA	DETAIL AREA	NO.	REQUIREMENT NAME
UMBRELLA	Umbrella	55	Datacentric Architecture
		56	Computer-Automated as Well as Computer-Aided
		57	Interoperability of Software
		58	Open Software Architecture
		59	Accessible Database Architecture
		60	Remote Networking Capability
		61	Full Data Access (Read Only) to All Project Participants
		62	Assignment of Data Ownership
		63	User-Friendliness
		64	Enterprise Product Model
		65	Integration With Simulation
		66	Information Management
		67	Scalability
		68	Transportability
		69	Configuration Management
		70	Compliance with Data Exchange Standards

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